EFFECTS OF CUTTING TOOL COATING ON SURFACE ROUGHNESS IN MACHINING PRE-HARDENED STEEL (P20)

AINI RUSHDA BINTI MD DESA

A thesis submitted is fulfillment of the requirements for the award of the degree of Bachelor of Manufacturing Engineering

Faculty of Manufacturing Engineering

Universiti Malaysia Pahang

JUNE 2012

ABSTRACT

Quality of surface roughness is one of the challenges in the industry to produce high quality products. Cutting parameters and type of cutting tools are the factors that affect the quality of surface roughness. The purpose of this study is to examine the influences of different types of cutting tools coating and cutting parameters on the surface roughness. The cutting tools used are (TiN, TiCN and TiAlN). Taguchi method is used with three factors and three levels which is spindle speed (500. 1000, 1500) rpm, feed rate (500, 800, 1000) mm/min and diameter tool size (8, 10, 12) mm. The experimental results showed that, with larger diameter tool size the value of surface roughness will decrease. Same goes to spindle speed. When increasing spindle speed from (500-1500) rpm, the value of surface roughness also decreases. Different results surface roughness in feed rate, lower feed rate will produce better surface roughness. With suitable cutting parameters, TiAlN showed in decreasing surface roughness compare to the other two types of cutting tools. Confirmation test had verified that Taguchi design was successful in investigating the effect type of cutting tool coating on the surface roughness.

ABSTRAK

Kualiti kekasaran permukaan adalah salah satu cabaran dalam industri untuk menghasilkan produk yang berkualiti tinggi. Parameter mesin dan jenis salutan pada alat pemotong adalah faktor yang memberi kesan pada kekasaran permukaaan. Tujuan kajian ini adalah untuk mengkaji pengaruh jenis salutan pada alat pemotong dan parameter mesin terhadap kekasaran permukaan. Alat pemotong yang di gunakan ialah (TiN, TiCN, TiAlN). Kaedah Taguchi di gunakan dengan menggunakan tiga faktor dan tiga tahap bagi kelajuan penggumpar (500, 1000, 1500) rpm, kadar suapan (500, 800, 1000) mm/min dan saiz alat pemotong (8, 10, 12) mm. Keputusan eksperimen menunjukkan apabila menggunakan saiz alat pemotong yang besar, nilai kekasaran permukaan juga akan berkurang. Apabila kelajuan alat pemotong tinggi dari (500-1500) rpm, nilai kekasaran permukaan juga akan berkurang. Keputusan kekasaran permukaan berbeza pada kadar suapan, kadar suapan yang lebih rendah akan menghasilkan kekasaran permukaan yang lebih baik. Dengan menggunakan parameter yang sesuai, TiAlN menghasilkan kekasaran permukaan yang lebih baik berbanding menggunakan dua lagi jenis salutan alat pemotong. Ujian pengesahan yang di lakukan mengesahkan bahawa kaedah Taguchi yang digunakan berjaya dalam mengkaji kesan jenis salutan alat pemotong pada kekasaran alat pemotong.

TABLE OF CONTENTS

			PAGE
ACKNOWLEDGEMENT			v
ABSTRACT			vi
ABSTRAK			vii
TABLE OF CONTENTS			viii
LIST OF TABLES			xi
LIST OF FIGURES			xiii
LIST OF ABBREVIATION			xv
CHAPTER 1	**INTRODUCTION**		
	1.1	PROJECT MOTIVATION	1
	1.2	PROJECT BACKGROUND	1
	1.3	PROBLEM STATEMENT	2
	1.4	PROJECT OBJECTIVES	2
	1.5	PROJECT SCOPES	3
	1.6	REPORT ORGANIZATION	4
CHAPTER 2	**LITERATURE REVIEW**		
	2.1	MILLING MACHINE	5
		2.1.1 Milling Process	5
		2.1.2 Milling Parameters	9
	2.2	MILLING CUTTER	10
		2.2.1 End Mill	10
		2.2.2 Coated Milling Cutter	11
	2.3	SURFACE ROUGHNESS	13
	2.4	TAGUCHI METHOD	15
	2.5	PRE-HARDENED STEEL (P20)	16

CHAPTER 3 METHODOLOGY

3.1 INTRODUCTION 18
3.2 MATERIAL SELECTION 20
3.3 EXPERIMENTAL 21
3.3.1 Determining suitable working levels of the design factors 23
3.3.2 Selecting proper orthogonal array 23
3.3.3 Experiment 24
3.3.4 Data Analysis 26
3.3.5 Verification Test 27

CHAPTER 4 DATA ANALYSIS AND DISCUSSION

4.1 INTRODUCTION 28
4.2 REGRESSION ANALYSIS 30
4.2.1 TiN coated cutting tool 31
4.2.2 TiCN coated cutting tool 32
4.2.3 TiAlN coated cutting tool 34
4.3 EFFECT OF PROCESS PARAMETER ON SURFACE ROUGHNESS 35
4.3.1 TiN coated cutting tool 35
4.3.2 TiCN coated cutting tool 36
4.3.3 TiAlN coated cutting tool 37
4.4 ANALYSIS OF SIGNAL TO NOISE 38
4.4.1 TiN coated cutting tool 39
4.4.2 TiCN coated cutting tool 40
4.4.3 TiAlN coated cutting tool 42
4.5 ANALYSIS OF VARIANCE (ANOVA) 43
4.5.1 TiN coated cutting tool 44
4.5.2 TiCN coated cutting tool 46
4.5.3 TiAlN coated cutting tool 47

4.6 VERIFICATION TEST 49

4.6.1 TiN coated cutting tool 49

4.6.2 TiCN coated cutting tool 50

4.6.3 TiAlN coated cutting tool 51

4.7 EFFECT OF TYPE OF CUTTING TOOLS COATING 52

CHAPTER 5 CONCLUSION AND FUTURE WORK

5.1 INTRODUCTION 54

5.2 CONCLUSION 54

5.3 RECOMMENDATION FOR FUTURE STUDY 55

REFERENCES 56

LIST OF TABLES

Table No.	Title	Page
2.1	Characteristic of TiN	12
2.2	Characteristic of TiCN	12
2.3	Characteristic of TiAlN	13
2.4	Machining Recommendations	17
3.1	Typical Chemical Analysis	20
3.2	Physical Properties	20
3.3	Physical Properties	21
3.4	Mechanical properties	21
3.5	Factors and Levels	23
3.6	Orthogonal Array	24
3.7	Parameter Setting At Surface Roughness Tester (Surfcom 130a)	25
3.8	Optimal Cutting Parameter	27
4.1	Surface Roughness Result and S/N Ratio for TiN	29
4.2	Surface Roughness Result S/N Ratio for TiCN	29
4.3	Surface Roughness Result S/N Ratio for TiAlN	30
4.4	Regression Analysis	31
4.5	Regression Analysis For TiCN	32
4.6	Regression Analysis For TiAlN	34
4.7	Response Table for S/N Ratios	39
4.8	Response Table For S/N Ratios (TiCN)	40
4.9	Response Table For S/N Ratios (TiAlN)	42

4.10	Analysis of Variance for Mean Ra, Using Adjusted Ss for Tests (TiN)	44
4.11	Analysis of Variance for Mean Ra, Using Adjusted Ss for Tests (TiCN)	46
4.12	Analysis of Variance for Mean Ra, Using Adjusted Ss for Tests (TiAlN)	47
4.13	Result of the Verification Test for Surface Roughness	49
4.14	Result of the Verification Test for Surface Roughness	50
4.15	Result of the Verification Test for Surface Roughness	51

LIST OF FIGURES

Figure No.	Title	Page
2.1	Milling process	6
2.2	Milling process	7
2.3	Milling process	8
2.4	Nomenclature of End Mill	11
2.5	Elements of Machined Surface Texture	14
3.1	Flow chart of overall methodology	19
3.2	Taguchi Design Procedure	22
3.3	Surface Roughness Tester (Surfcom 130a)	25
3.4	Measurement Surface Roughnes	26
4.1	Normal Probability Plot for TiN	31
4.2	Normal Probability Plot for TiCN	33
4.3	Normal Probability for TiAlN	34
4.4	Mean Surface Roughness vs. Spindle Speed, Feed Rate, and Tool Size (TiN)	35
4.5	Mean Surface Roughness vs. Spindle Speed, Feed Rate, and Tool Size (TiCN)	37
4.6	Mean Surface Roughness vs. Spindle Speed, Feed Rate, and Tool Size (TiAlN)	37
4.7	S/N Ratios vs. Spindle Speed, Feed Rate, and Tool Size (TiN)	39
4.8	S/N Ratios vs. Spindle Speed, Feed Rate, and Tool Size (TiCN)	41
4.9	S/N Ratios vs. Spindle Speed, Feed Rate, and Tool Size (TiAN)	42

4.10	Normal Probabilty Plot (TiN)	45
4.11	Normal Probabilty Plot (TiCN)	46
4.12	Normal Probabilty Plot (TiAlN)	48
4.13	Surface Roughness Vs Spindle Speed (TiN, TiCN, TiAlN)	52
4.14	Surface Roughness Vs Feed Rate (TiN, TiCN, TiAlN)	52
4.15	Surface Roughness Vs Diameter Tool Size (TiN, TiCN, TiAlN)	53

LIST OF ABBREVIATIONS

FYP	Final year project
TiN	Titanium Nitride
TiCN	Titanium Carbonitride
TiAlN	Titanium Aluminum Nitride
N	Spindle Speed
f_r	Feed Rate
C	Carbon
Si	Silicone
Mn	Mangan
Cr	Chromium
Mo	Molybdenum
ANOVA	Analysis Of Variance
v	Spindle Speed (rpm)
f	Feed Rate (mm/min)
d	Diameter Tool Size (mm)
DF	Degree of Freedom
Adj SS	Adjust Sum Square
Adj MS	Adjust Mean Square
F	Fisher's Ratio
P	Probabilty Value

CHAPTER 1

INTRODUCTION

1.1 PROJECT MOTIVATION

Surface finish is one of the important factor or requirement from the customer. The quality of the surface roughness is important to produce a precision mold. Without precision molds, there is no quality in producing a plastic product. This will adversely affect the industry. It is important to give a good characteristic of a part or product. A good characteristic is like a lower contact surface friction, light reflection, coating and resisting fatigue. Without lower surface roughness, all stated characteristics cannot be achieved. Therefore, a suitable cutting tool and cutting parameter is important to produce a better surface roughness.

1.2 PROJECT BACKGROUND

Milling machine is used to machine a solid material. In manual condition, milling machine can be used to machine any objects that are not axially symmetric. It also used to remove the unwanted material. Milling machine was widely used in many manufacturing industries including the aerospace and automotive sector. (Mike S.L et al, November 1998)

In this sector, quality plays an important role in increasing the productivity of the product. Surface finish or surface roughness is characteristic of the workpiece after machining. There are several factors that can affect the quality of surface roughness which is cutting speed, feed rate, depth of cut, type of tool and tool size (Mike S.L et al., November 1998).

Many research have been done to study the surface roughness. The studies used different methods towards the surface roughness. The methods are mathematical modeling and stylus profiler. By this method, the surface roughness can be measured.

1.3 PROBLEM STATEMENT

Several factors will affect the final result of surface roughness in CNC milling operation. The uncontrollable factor such as tool geometry, tool wear, chip loads and chip formation are the factor resulting in poor surface roughness. During the milling operation, chatter or vibration of the machine tool and wear will contribute to the damage of surface roughness.

The main point is stressed in this research is to choose a suitable cutting tool with a suitable parameter to produce a fine surface finish. Improper process parameters cause losses such as rapid tool wear and tool fracture besides the economic losses including spoiled workpiece or reduced surface quality (Gokkaya, H. et al. 2005).

The purpose of this research is to study the effect of the different type of cutting tools coating to the surface roughness together with the cutting parameters.

1.4 PROJECT OBJECTIVE

The objective of this research is to know the factors that affect surface roughness for machining the pre-hardened steel (P20). From the previous research had proved that different cutting tool coating produced different surface roughness. Beside that there are many machining parameters that are also contributing in the influenced of surface roughness.

These are the objectives of this research.

1. To study more about CNC milling machine
2. To analyze the effect of different type of cutting tools coating on the surface roughness
3. To determine the optimum cutting parameters in machining to produce better surface roughness.

1.5 PROJECT SCOPE

The scope of this project covers several issues from the milling machine, cutting tools coating used and the analysis.

1. **Different type of cutting tools coating.**
   Three types of cutting tool coating are used to determine the best type of cutting tool coating to produce the best surface roughness.
2. **Machining parameters.**
   Three types of machining parameters which is spindle speed, feed rate and diameter tool size is used to determine the optimal machining cutting for these parameters.
3. **Machining conditions.**
   Three level machining parameters are used which is high level, medium level and low level.

1.6 REPORT ORGANIZATION

This report is organized into five main chapters which is to explain the detailed information about the research.

1. **Introduction**

   This chapter discussed the information in term of background, problem statement, objectives, scopes and others. This chapter is important because it is used to give the general idea about this project.
2. **Literature review.**

   In this chapter, detailed information about this project is discussed. Some of the information is about milling machine, milling cutter, surface roughness and others.
3. **Methodology.**

   The design of experiments is discussed in this chapter. The method used is discussed in detail to show how the project is done.
4. **Result and discussions.**

   Result obtains from the experiment are shown in this chapter. The result is shown in term of table and graph. Then the data are analyzed and compare.
5. **Conclusion and recommendations.**

   This chapter summarized the overall of this project and determines whether the objectives of this project achievable or not. Recommendations for future study are also stated in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 MILLING MACHINE

Milling machine is a versatile machine. Milling machine not only machine flat surface but it also can perform other operations which are drilling, boring, reaming, threading and taping. Milling machine can be divided into two types known as horizontal milling machine and vertical milling machine.

Previously, milling machine was introduced by Eli Whiteney in the year of 1818. Milling machine was introduced in New Heaven Connecticut. (Meyers A.R et al, 2001).

2.1.1 Milling Process

In milling operation, the workpiece is fed pass through a rotating cutting tool that have been mounted on the spindle. The axis rotation of the tool is perpendicular to the feed direction. Milling cutter or cutting tool is the name that usually used in the industry for the tool used. Usually the plane surface is created through milling.

Many operations can be performed by using a milling machine. Each of these operations needs a suitable milling cutter in machining. It is important to use a suitable size of milling cutter because the size of milling cutter can also contribute to the machining surface finishing. The cutting tools with greater radius cause smaller surface roughness values (Tawfiq, 2008).

Before the machining operations were started, a suitable material and cutting tool must be chosen to withstand cycles of impact forces and thermal shocked (Marinov.V. 2011). Different types of milling operations are shown in Figure 2.1.

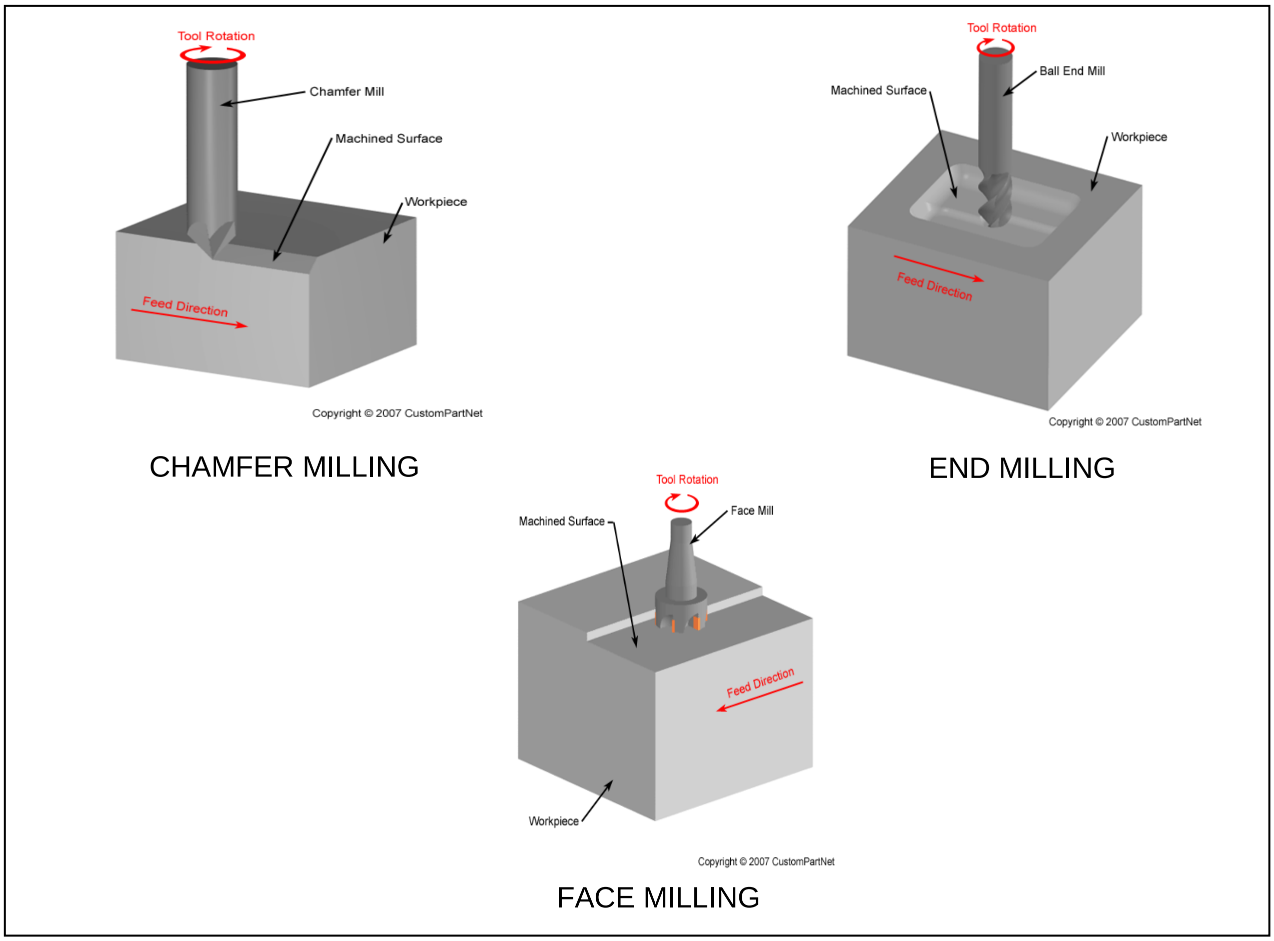

FIGURE 2.1: Milling Process

(http://www.custompartnet.com/wu/milling#design_rules)

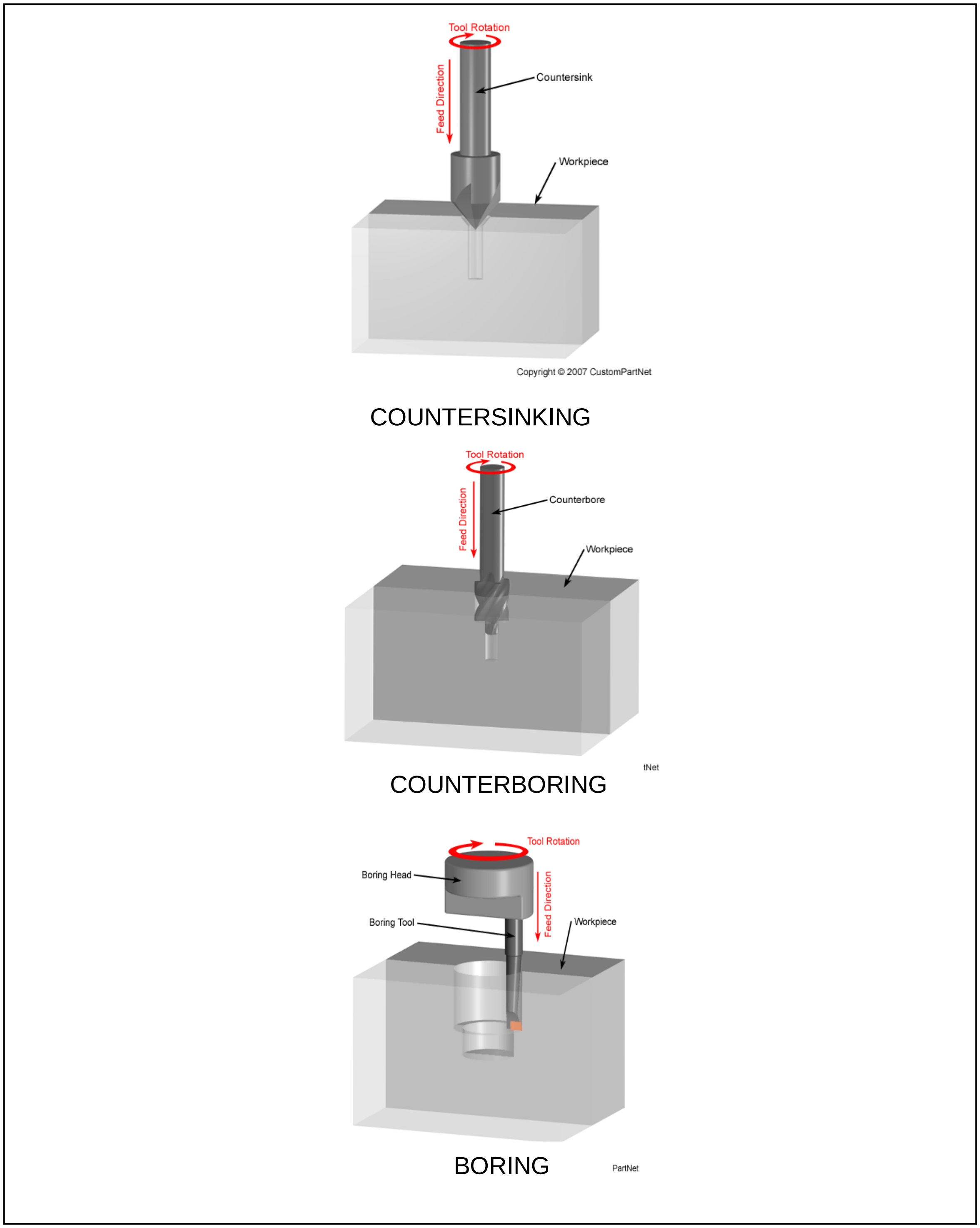

FIGURE 2.2: Milling Process

(http://www.custompartnet.com/wu/milling#design_rules)

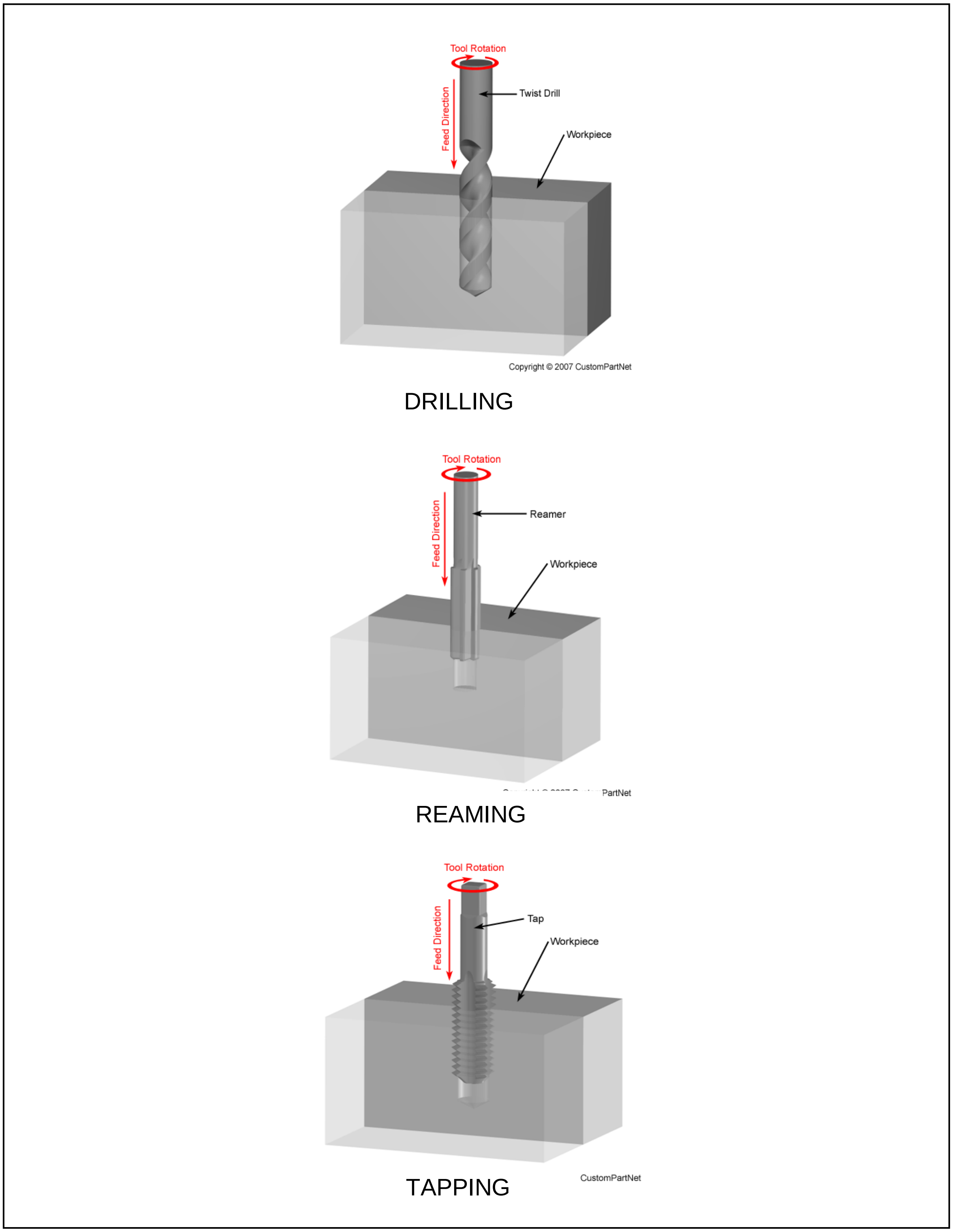

FIGURE 2.3: Milling Process

(http://www.custompartnet.com/wu/milling#design_rules)

2.1.2 MILLING PARAMETERS

In milling, there are several parameters should be considered before starting the machining operation. These parameters are selected due to workpiece material, type of cutting tool, cutting tool size and more. (http://www.custompartnet.com/wu/milling)

- Cutting speed -the velocity of the tool as it cuts the material.
- Cutting feed – the distance that the cutting tool cut the workpiece in one revolution of the spindle and tool. For a multipoint tool, the cutting feed is also equal to the feed per tooth.
- Spindle speed – the speed of spindle and tool in revolution per minute. The spindle speed is equal to the cutting speed divided by the circumference of the tool. The spindle is measured by revolution per minute (RPM).

$$N = \frac{v}{\pi D}$$

Where

N = spindle rotation speed (RPM)

v = cutting speed (in/min)

D = outside diameter of cutter (in)

- Feed rate – the speed of cutting tool toward the workpice as the tool makes a cut.

$$f_r = N n_t f$$

Where

f_r = feed rate (mm/min or in/min)

N = spindle rotation speed (RPM)

n_t = number of teeth

f = chip load (in/tooth or mm/tooth)

2.2 MILLING CUTTER

Milling cutters are one of the most important elements in milling process. Milling cutter helps in cutting different materials. Milling cutter is usually made of high speed steel.

2.2.1 End Mill

End mill is a type of milling cutter. Usually, end mill is a cutting tool that is used in an industrial milling application. It is a sharp milling cutter that will be rotated by the spindle. The cutter is a cylindrical tool with sharp teeth and there is a space between the teeth around the exterior. The space between the teeth is called flute and its function to remove all the chips form during machining from the work piece. Figure 2.2 shows the end mill nomenclature. The number of flutes that usually used is two and four flute end mill. The two flute end mill allows maximum space for chip ejection. It is generally used in the milling machine. Three flute end mill is used for general milling operation and its give excellent for slotting. End mill with 4, 5, 6, and 8 flutes can be used to improve the surface roughness if the feed rate remains constant. It is because a greater number of flutes reduces chip load. The end milling cutter can be categorized by the number of flutes, material, helix angle, and coating material. It also can be categorized by specific application and special geometry.

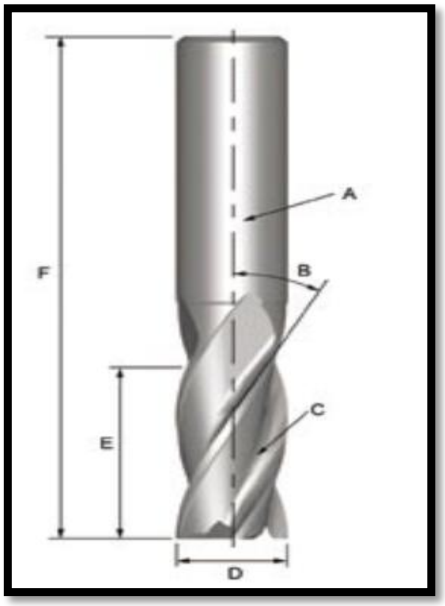

Figure 2.4: Nomenclature of End Mill
(Bray,S. 2004)

Where

A	Shank
B	Helix Angle
C	Flute
D	Outer Diameter
E	Cutting Length
F	overall Length

2.2.2 Coated Milling Cutter

During machining, milling cutter tends to wear. In order to avoid milling cutter to wear easily, coating is applied to milling cutter. The main function of coating is to reduce wear and friction. Titanium nitride (TiN), Titanium Carbonitride (TiCN), Titanium Aluminum Nitride (TiAlN), TiAlCrN, AlTiCrN and AlCrTiN (PVD coating) are types of coating usually used in industry. The advantages of applying coating at the tool are to increase tool life, reduce downtime, allow higher feed and speed rate and reduce tooling cost per job. Without correct tool choice, coating choice, the part material, tool rigidity, machine parameter will reduce the coating advantage as mention above (Park, H.O. 2012).

Titanium nitride (TiN) is produced in gold color. It is used for better tool life during machining mild steel, stainless steel and lnconel. The surface hardness of TiN is about 80 Rc. TiN has a very good corrosion resistance, heat transmission and excellent wear resistance. Characteristic of TiN is shown in the table below.

Table 2.1: Characterisctic Of TiN

Hardness	2800 HV
Thermal stability	550 °C / 1000F

Titanium carbonitride (TiCN) can be found in medium gray or bronze color. The hardness of TiCN is reaching 90 Rc. The benefits of using TiCN are improved surface roughness, improved wear resistance on abrasive, adhesive or material hard to machine. Depending on the application, coolant, machined parameter, and other condition, the speed and feed rate can be increased and tool life can be improved.

Table 2.2: Characterisctic of TiCN

Hardness	3000HV
Thermal stability	400 °C / 750 F

The color of Titanium Aluminum Nitride (TiAlN) is purple/black. The surface hardness of TiAlN is upper 80 Rc. Compared to TiN coating and TiCn coating, TiAlN coating produce less coefficient friction and the performance of TiAlN are good in machining abrasive and material hard to machine such as cast iron, aluminum alloy, tool steels and nickel alloy.

Table 2.3: Characterisctic of TiAlN

Hardness	2800HV
Thermal stability	750 / 1350 F

2.3 SURFACE ROUGHNESS

Surface roughness is the surface texture of the material after machining. In machining industry, quality plays an important role in order to meet the customer requirement. Quality is closely related to the surface roughness. There are several factors influencing the surface roughness such as cutting speed, feed rate and depth of cut (Tawfiq M. A et. al.,2008).

Gokkaya H. et al. (2005) state that surface roughness is affected by the cutting tool coating material, cutting speed and feed rate. The surface roughness can be measured by using a surface roughness tester. A good combination of cutting speed and feed rate can provide better surface qualities (Gokkaya, H. et. al, 2005).

A wide variety of surface textures are generated by machining process. Repetitive and/or random deviation from the ideal smooth surface forms the surface texture. These deviations are (Marinov,V. 2011).

- Roughness: small, finely spaced surface irregularities (micro irregularities)
- Waviness: surface irregularities of grater spacing (macro irregularities)
- Lay: predominant direction of surface texture